

APPENDIX-A

LIQUID PHASE ADSORBER DESIGN EXAMPLE

A-1. Problem. Given the following pilot study information, design a liquid phase granular activated carbon (GAC) adsorption system for treating RDX-contaminated groundwater.

a. Background data.

(1) *Given.*

- Flow rate: 15.8 L/s (250 gpm)
- Contaminant concentration influent: 69 ug/L
- Contaminant concentration effluent: 4 ug/L

(2) *Determine.*

- Surface loading rate.
- Empty bed contact time and number of columns.
- Column nominal diameter and mass of GAC/column.
- Bed depth.
- Volume of water treated per change out period.

b. Isotherm evaluation. A number of carbons were evaluated on the basis of isotherm results, and the most promising carbon was selected for the pilot test and the results of the test are graphically presented in Figure A-1. A second option to this process is to hire an independent laboratory to conduct accelerated carbon column pilot testing, evaluate several carbons, and recommend one.

c. Pilot test. Based on Figure A-1, the number of bed volumes versus the concentration at which the effluent reaches our maximum allowable concentration of 4 µg/L is 22,000. Comparing the number of bed volumes treated using two columns in series, we see the number of bed volumes treated before breakthrough equals 54,000, or approximately 145% more bed volumes than using a single column. Using two columns in series, each with a detention time of 2 min-

utes, means that the first column will be nearly exhausted with the effluent concentration corresponding to $67/69 \times 100 = 97\%$ of the influent concentration. To most effectively use the carbon in a system with two columns in series, the detention time in each column should be 6 minutes. This will ensure that the lead column GAC is fully exhausted before the adsorption zone passes completely through it and before to the effluent in the lag column reaches the maximum allowable concentration. The pilot plant information is provided in Table A-1.

Table A-1
Pilot plant data

Carbon Sample	XYZ Carbon Company
Column Inside Diameter	108 mm (4.25 in. [0.354 ft])
Column Area	9150 mm ² (0.0985 ft ²)
Bed Volume	5.56 L (0.197 ft ³ [1.47 gal])
Flow Rate	2.84 L/m (0.75 gpm)
Hydraulic Loading	310 Lpm/m ² (7.6 gpm/ ft ²)
Bed Depth	0.61 m (2 ft)
EBCT (each column)	2 min
RDX Influent Conc	69 µg/L
Weight of GAC per Column	2.32 kg (5.1 lb)
Weight of RDX per Column	14.2 g (0.0310 lb)
Run Time	150 days

A-2. Solution.

a. Surface Loading Rate. The surface loading rate is given by the pilot test, but as a rule of thumb, the rate should be between 80–400 Lpm/m² (2–10 gpm/ft²). The range of the pilot is near the high side of the range, so the system will be sized to limit the hydraulic loading rate to 310 Lpm/m² (7.6 gpm/ ft²), but will be sized to accommodate standard sized vendor equipment. The diameter and resultant surface loading rate are calculated below.

b. Empty Bed Contact Time (EBCT) (Pilot Test). The contact times used vary by type of contaminant, but generally are in the 2–20 minute range, depending of course on the contaminant. The 2-minute contact time per column provided by the GAC pilot system limited the potential adsorbance by the GAC. The pilot data (Figure A-1) indicate a significant increase in the mass of RDX adsorbed per unit weight of carbon based on a minimum contact time of 4 minutes (2 minutes per column times two columns), and an even greater increase for a contact time of 6 minutes. A contact time based on GAC equipment size with a minimum contact time of 6 minutes per bed (assuming two beds in series) will be used.

c. Nominal Column Diameter. Diameter is equal to the flow rate 15.8 L/s (946 L/m) (250 gpm) divided by the loading rate, 310 Lpm/m² (7.6 gpm/ft²) or 3.05 m² (32.9 ft²), which equates to $(4 \times A/B)^{0.5} = 1.97$ m (6.5 ft) in diameter. Referring to manufacturers literature, we find that the nearest diameter unit is either a 1.54-m (5-ft) or a 2.4-m (8-ft) diameter unit. A 2.4-m (8-ft) diameter unit has an area equal to 4.67 m² (50.3 ft²), which makes our loading rate = $[(946 \text{ L/m})/4.67 \text{ m}^2] = 203 \text{ Lpm/m}^2$ (250 gpm/50.3 ft² or a 5.0 gpm/ft² loading rate). This is in the normal 80–400 Lpm/m² (2–10 gpm/ft²) range. A 1.54-m (5-ft) diameter unit has an area equal to 1.86 m² (19.6 ft²), which makes our loading rate = $[(946 \text{ L/m})/1.86 \text{ m}^2] = 509 \text{ Lpm/m}^2$ (250 gpm/19.6 ft² or a 12.75 gpm/ft² loading rate). This is above the normal 80–400 Lpm/m² (2–10 gpm/ft²) range. So, two 8-ft diameter units will be selected.

d. Bed Depth. A minimum of 6 minutes/column should be used: 6-minute EBCT $\times 0.946 \text{ m}^3$ = a minimum carbon contact volume of 5.68 m³ (1500 gal/7.48 gal/ft³ = 200 ft³). Bed depth is equal to the bed volume divided by the column area or $5.68 \text{ m}^3/4.67 \text{ m}^2 = 1.22$ m (200 ft³/50.3 ft² or 4 ft). By referring to Figure A-1, we see that the adsorption zone slightly exceeds the 1.22-m (4-ft) bed depth (two columns $\times 0.61$ m of GAC/column), and the effluent concentration in the first column is slightly less than the influent concentration. The RDX concentration in the effluent of the third column does not exceed the 4 µg/L until well into the test (approximately 110,000 bed volumes). Again, manufacturer literature gives the amount of carbon per bed to be generally about 4535 kg (10,000 lb), which corresponds to a bed depth of 2.3 m (7.5 ft) for the 2.44-m (8-ft) diameter columns. The resulting EBCT is, therefore:

$$\frac{2 \text{ beds} \times 4535 \text{ kg of GAC per bed}}{420 \text{ kg/m}^3 \text{ of GAC}} = 22 \text{ m}^3 \text{ of GAC (770 ft}^3\text{)}$$

$$\frac{22 \text{ m}^3 \text{ of GAC}}{(0.946 \text{ m}^3/\text{minute})} = 23 \text{ minutes}$$

e. Anticipated Volume of Water Treated per Change out Period. Contact time for the pilot was 6 minutes. Actual contact time is $23/6 \times 100$ or 383% longer. The change out period for the full-scale system can be approximated by multiplying the ratio of the difference in the contact time by the pilot test run time to breakthrough.

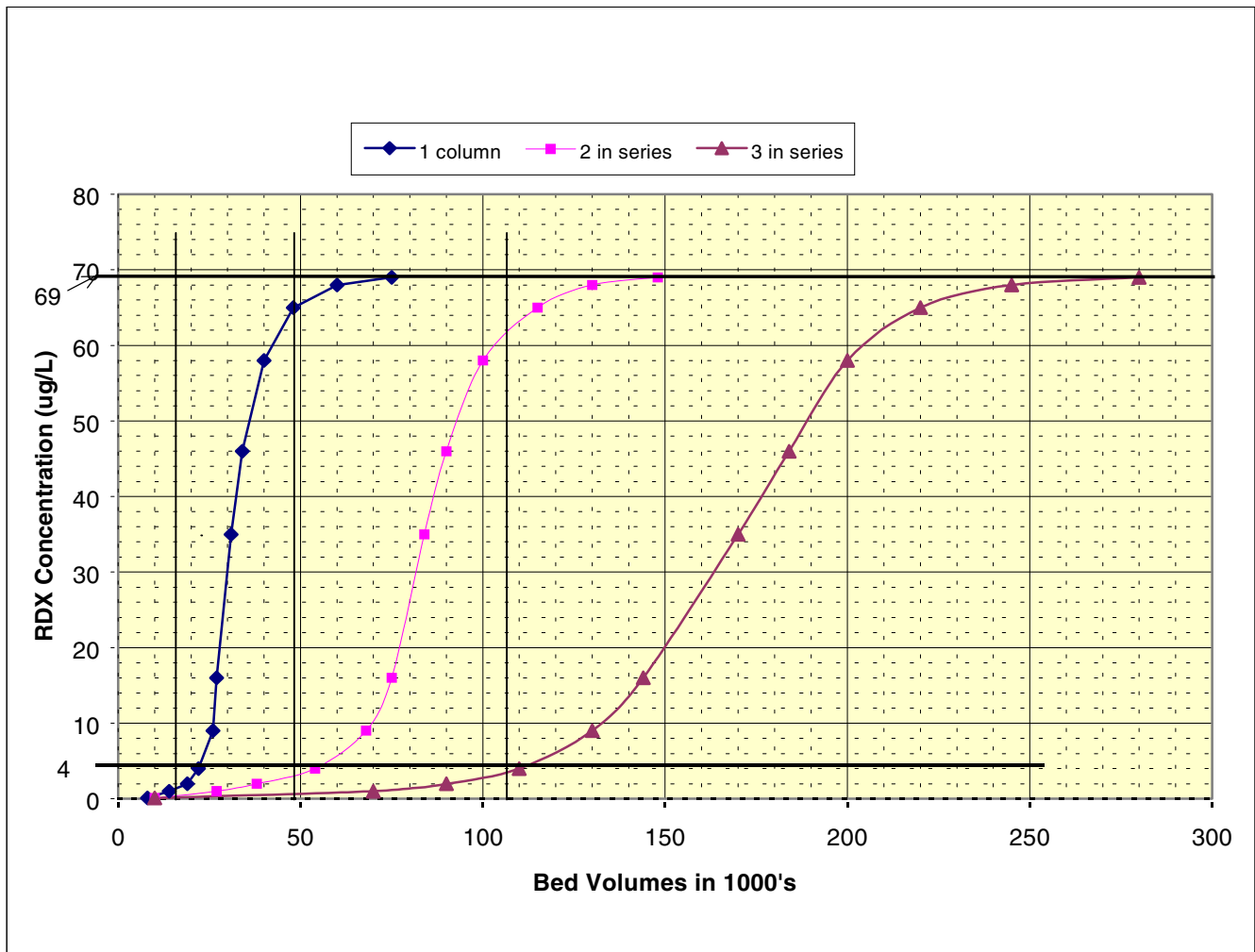


Figure A-1. Example.

f. Optional Method One.

- Breakthrough period: $3.83 \times 150 \text{ days} = \sim 574 \text{ days}$ (**~ 19 months**)
- Volume treated:

$$574 \text{ days} \times (0.946 \text{ m}^3/\text{min}) \times (1440 \text{ min/day}) = \mathbf{781,925 \text{ m}^3} \text{ (} 2.07 \times 10^8 \text{ gal)}$$

g. Optional Method Two.

- Estimated carbon usage for a single bed:

$$22,000 \text{ bed volumes} \times 5.56 \text{ L/bed volume} = 122,320 \text{ L (39,660 gal)}$$

$$2.32 \text{ kg GAC} \times 1000 \text{ g/kg} = 2320 \text{ g (5.1 lb)}$$

$$2320 \text{ g}/122,320 \text{ L} = 0.0190 \text{ g/L or } 19.0 \text{ g}/1000 \text{ L (0.16 lb}/1000 \text{ gal)}$$

- Estimated carbon usage for two beds in series:

$$54,000 \text{ bed volumes} \times 5.56 \text{ L/bed volume} = 300,240 \text{ L (79,320 gal)}$$

$$4.64 \text{ kg GAC} \times 1000 \text{ g/kg} = 4640 \text{ g (10.2 lb)}$$

$$4640 \text{ g}/300,240 \text{ L} = 0.0155 \text{ g/L or } 15.5 \text{ g}/1000 \text{ L (0.13 lb}/1000 \text{ gal)}$$

- Estimated carbon usage for three beds in series:

$$110,000 \text{ bed volumes} \times 5.56 \text{ L/bed volume} = 611,600 \text{ L (161,600 gal)}$$

$$6.96 \text{ kg GAC} \times 1000 \text{ g/kg} = 6960 \text{ g (15.3 lb)}$$

$$6960 \text{ g}/611,600 \text{ L} = 0.0113 \text{ g/L or } 11.3 \text{ g}/1000 \text{ L (0.06 lb}/1000 \text{ gal)}$$

- Anticipated volume of water treated per changeout period using 11.3 g/1000 L treated:

$$\text{Carbon volume: } 9,070 \text{ kg or } 9,070,000 \text{ g}$$

$$\text{Utilization rate: } [9,070,000 \text{ g}/(11.3 \text{ g}/1000 \text{ L})] = 8.03 \times 10^8 \text{ L (} 2.1 \times 10^8 \text{ gallons)}$$

$$8.03 \times 10^8 \text{ L}/(946 \text{ L/min}) = 849,000 \text{ minutes}$$

$$849,000 \text{ min} \times (1 \text{ day}/1440 \text{ min}) \times (1 \text{ month}/30 \text{ days}) = \sim \mathbf{19 \text{ months}}$$